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A NEW METHOD OF MEASURING SHORT HALF-LIVES

Abstract of

A Thesis

Presented in Partial Fulfillment of the Requirements for
the Degree Master of Science

By

DELBERT SYLVESTER BARTH, B.S.

The Ohio State University

1952

Approved by:

Advisor

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A NEW METHOD OF MEASURING SHORT HALF-LIVES

DELBERT SYLVESTER BARTH

B.S., United States Military Academy, 1946

Department of Physics
(Approved by James C. Harris)

A review of several methods of measuring the half-lives of short-lived radioisotopes is presented. Then a new method is described which utilizes a cathode ray oscilloscope in conjunction with three phototubes and associated electrical circuits. The design and construction of the concomitant apparatus is taken up in detail. The method described is then applied to the specific problems of measuring the half-lives of the isotopes aluminum twenty-five and aluminum twenty-six, which result from the bombardment of magnesium twenty-four and magnesium twenty-five respectively with protons accelerated by a Van de Graaff generator. The values obtained for the half-lives are reported as follows: aluminum twenty-five -- seven and eleven hundredths seconds plus or minus thirteen hundredths of a second; aluminum twenty-six -- seven and sixty-one hundredths seconds plus or minus twenty-one hundredths of a second. In conclusion the capabilities and limitations of the new method described are delineated, and future applications are suggested.

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Historical Review and Introduction

Before proceeding to a description of a new method of measuring the half-lives of short-lived radioisotopes it is perhaps advisable to describe some of the methods which have been used successfully in the past. In this regard Edwards(1) has given an excellent review of several methods, some of which will now be discussed.

Attempts to measure the half-life of Ra C' (1.53×10^{-4} sec.) gave rise to three different methods of measuring short half-lives, all of which depend on the radioactive daughter isotope of interest being formed from a radioactive parent whose half-life is long compared to that of the daughter. These methods may be called (1) the pulse-lengthening method, (2) the delayed pulse method, and (3) the oscilloscope method.

The pulse-lengthening method has been developed by Dunworth(2) and Rotblat.(3), (4) It utilises two counters, one of which is sensitive to the beta radiation from Ra C and one of which is sensitive to the alpha radiation from Ra C'. The pulses from the two counters are amplified separately, made of uniform size, and then fed into a coincidence circuit. The length of the beta pulses is varied and the number of coincidences per unit time observed as a function of the length of the pulse. That the graph of the coincidences per unit time versus the length of the pulse is the inverse of

the Ra C' decay curve may be seen from the considerations below.

The general law of radioactive decay may be written as

$$N = N_o e^{-\lambda t} \qquad (1)$$

where N = the number of atoms of a radioactive material remaining at the end of a time t ; N_o = the initial number of atoms; and λ = the decay constant.

If N_o be put equal to one and the differential of (1) taken, the result is

$$d\,N = -\lambda e^{-\lambda t}\,dt \qquad (2)\ .$$

From (2) it may be seen that the probability for a given atom to live a time t and then decay in the interval from t to t+dt is $\lambda e^{-\lambda t}dt$. Thus the probability for the emission of an alpha particle during the time τ, or what is the same thing, the rate of coincidence when the beta pulse has a length τ is

$$C = N_o \int_0^{\tau} \lambda\, e^{-\lambda t} dt \qquad (3)$$

where λ is the decay constant of Ra C' and N_o is the initial number of Ra C' atoms.

Evaluating the integral in (3) leads to

$$C = C_{max}\ (1-e^{-\lambda\tau}) \qquad (4)$$

where C_{max} is the maximum coincidence rate, which will be attained when τ becomes infinite. For infinite τ, $C = C_{max} = N_o$. From (4) it can be seen that the coincidence rate increases exponentially with the beta-pulse length in a manner

determined by the decay constant λ. Hence it is possible to compute the half-life of Ra C' from the experimental relationship observed between the coincidence rate and the length of the beta pulse.

The delayed pulse method has been developed by Jacobsen and Sigurgeirsson (5). As in the previous method two counters are used, one sensitive only to beta radiation and the other sensitive only to alpha radiation. The outputs of the two counters are fed into a coincidence circuit as before. Now, however, instead of lengthening the beta pulse the arrival of the beta pulse is delayed a variable length of time. As before the probability that an atom decays in the interval between t and t+dt is $\lambda e^{-\lambda t}\,dt$. When the pulse widths are short compared to the half-life being measured this is equivalent to the probability that a coincidence be recorded after the beta pulse has been delayed t units of time. Therefore the coincidence rate may now be expressed as

$$C = N_0\int_{\tau}^{\tau+\tau_c}\lambda e^{-\lambda t}\,dt \qquad (5)$$

where τ is the delay time of the beta pulse; τ_c is the maximum length of time by which two pulses may be separated and still be recorded as a coincidence; λ is the decay constant of Ra C' ; and N_0 is the initial number of Ra C' atoms. Integration of (5) gives

$$C = N_0 e^{-\lambda\tau}\left(1-e^{-\lambda\tau_c}\right) \qquad (6).$$

If one now denotes by C_0 the value of C when $\tau = 0$, it is

easily seen that

$$N_0 = C_0/(1 - e^{-\lambda\tau_c}) \qquad (7)\ .$$

With this substitution (6) becomes

$$C = C_0\ e^{-\lambda\tau} \qquad (8)\ .$$

From (8) it is clear that a graph of the observed rate of coincidence versus the delay time of the beta pulses will give a decay curve for Ra C' from which the half-life may be easily computed.

The oscilloscope method has been developed by Rowlands. (6),(7) Two counters are used as in the previous two methods. This method does not, however, utilize a coincidence circuit. Instead, the beta pulse is used to trigger a single sweep on a cathode ray oscillograph and the alpha pulse is applied to the vertical deflection plates. By this means it is possible to observe directly the time intervals between pulses simply by noting the position of the alpha pulse on the oscillograph screen. The number of alpha pulses observed after a time delay τ will be

$$N = N_0 \int_{\tau}^{\tau+\Delta\tau} \lambda e^{-\lambda t}\, dt \qquad (9)$$

where $\Delta\tau$ is the smallest unit of time observable on the oscillograph time scale being used; λ is the decay constant of Ra C' and N_0 is the initial number of Ra C' atoms. As in the delayed pulse method this may be readily integrated to give

$$N = N_0'\ e^{-\lambda\tau} \qquad (10)$$

where now N_0' is the number of alpha pulses having a zero time

delay; by analogy to (7) N_0' is equal to $N_0\ (1-e^{-\lambda\Delta\tau})$. So it is evident that a plot of alpha pulses versus observed delay times will give a decay curve for Rn C' from which the half-life can be easily determined.

It appears on the surface as though none of the three methods just described could be utilized to measure the half-life of a radioactive isotope which is the sole product nuclei of, say, a nuclear reaction and which decays to a stable isotope. Actually, however, De Benedetti and McGowan(28) have shown that the delayed pulse method may be used to measure the half-life of a single isolated radioactive material. Several other methods also applicable to this case will now be discussed.

In a method originated by Moseley and Fajans(8) and developed by Becker and Gaerttner(9) a target is deposited on a disk which rotates at high speed. The target is then bombarded with nuclear projectiles from some sort of an accelerator, and the activity is measured as a function of the angular displacement from the point of bombardment. From this data the half-life of the activity may easily be computed.

Cassels and Latham(10) have used a cyclotron modulated to give short bursts of particles. In between the bursts, the counter measuring the radioactivity of the target is connected in turn for equal time intervals to each of ten

separate recorders. The half-life of the activity may then be easily computed from the data obtained. Daniels and Latham claim that this method is good for half-lives ranging from 100 microsec. to 1 sec. The factor which sets a lower limit to the half-life measurable by this technique is the recovery time of the counter being used to measure the activity. The use of scintillation counters, which have recovery times on the order of 10^{-8} sec., would increase the range of applicability of this method considerably.

For half-lives longer than a few seconds, a target may be bombarded and then removed to an adjacent counter of some sort which measures the activity and the decay of the induced radioactivity. The main difficulties in this procedure are getting the radioactive target from the place of bombardment to the counter before the activity has decayed too much, and devising a timing mechanism to accurately fix the time intervals during which the counter counts. The number of counts obtained must also be recorded in some fashion. The counting interval should, of course, be reasonably small compared to the half-life being measured. Different research workers(1),(11),(12) have devised various methods to surmount the difficulties mentioned. For more specific information the literature may be consulted.

In general the methods for measuring short half-lives just described have limited ranges of applicability and require complicated electronic circuits which are not avail-

able commercially. The new method which will be described in this thesis has a range of applicability from approximately 1 millisec. to 1 min. and utilizes for the most part commercially available equipment. The associated electrical circuits which must be constructed are simple in design and not difficult to assemble. Although the method was designed for use with a Van de Graaff generator, it could easily be adapted for use with any other type of accelerator. After the general theory and construction of the equipment have been discussed, descriptions of two experiments utilizing the method will be given. The results of these experiments will be discussed and finally future applications of the method will be suggested.

General Description of Method and Equipment

The method discussed below was devised for use with the Van de Graaff generator at Ohio State University. A general description of the pieces of equipment necessary and the tasks performed by each follows.

A shutter was constructed to interrupt the Van de Graaff generator beam. Simultaneously with interrupting the beam the shutter actuates a microswitch which in turn actuates a relay raising a lead shield from between the target being bombarded and an active Geiger tube. The pulses from the

[illegible]

[illegible]

[illegible]

[illegible]

Geiger tube are fed into the vertical deflection plates of a cathode ray oscilloscope. The microswitch mentioned before also closes an electric circuit which triggers a single sweep of the electron beam across the face of the oscilloscope. Positioned at definite intervals along the time axis of the oscilloscope are three lucite tubes which pipe light to three separate type 931-A photomultiplier tubes. Each photomultiplier tube is followed by its own preamplifier and its own independent scaler. Thus during a single sweep of the electron beam across the face of the oscilloscope a certain number of pulses will be "seen" by each phototube and recorded on the appropriate scaler. This will give three points on a decay curve of the activity being counted. Of course, this routine must be gone through many times to obtain sufficient counts on each scaler to give a small probable error. The time base of the oscilloscope sweep must be adjusted to a value commensurate with the half-life of the activity being measured.

It is seen from the preceding description of the new method that the equipment necessary is:

(1) A Van de Graaff generator.

(2) A shutter for interrupting the Van de Graaff generator beam.

(3) A Geiger tube.

(4) A cathode ray oscilloscope.

(5) Three phototubes with individual preampli-

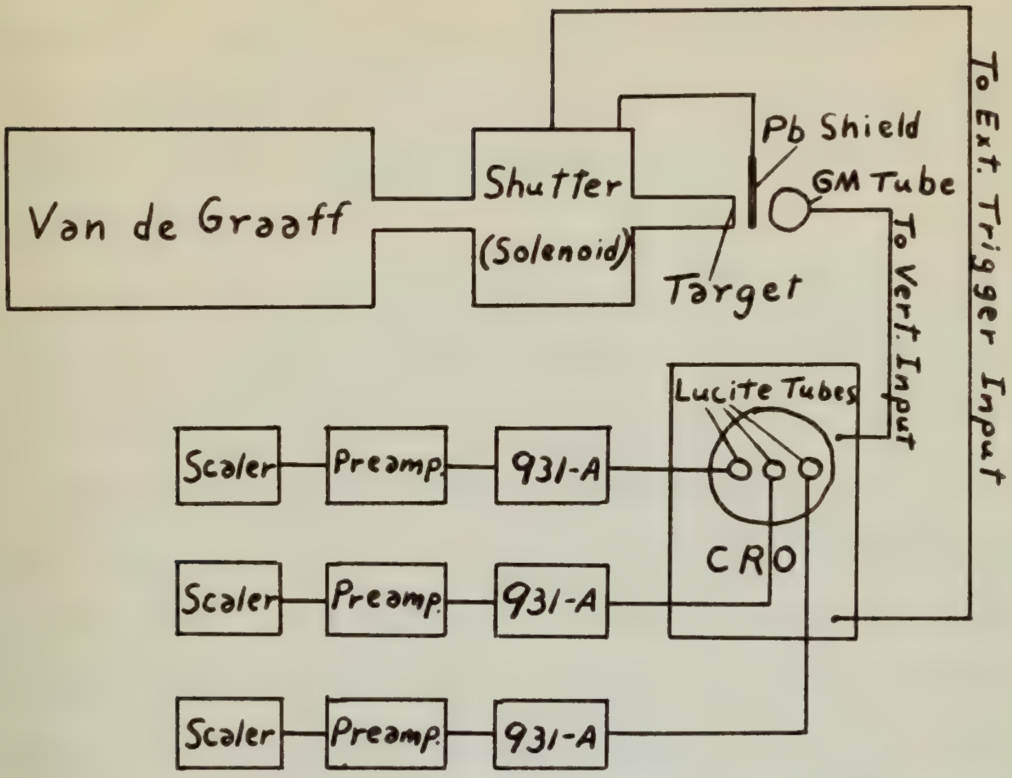

Figure 1. Sketch of arrangement of various equipment.

fiers and independent outputs.

(6) Three scalers.

(7) Various voltage supplies.

Figure 1 is a sketch illustrating the proper relationship of this equipment. Items (2) and (5) in the above list require a special description since they had to be designed and constructed.

Figure 2 is a sketch of the shutter used in this work. As can be inferred from the sketch the activating force for the shutter is provided by a solenoid. When this solenoid is actuated by a hand switch in series with a 200 volt D. C. power supply the soft iron core is drawn inside the solenoid, cutting off the Van de Graaff beam and actuating the micro-switch. The solenoid draws 70 milliamperes of current. When the hand switch is turned off a spring draws the shutter back so that the Van de Graaff beam is again bombarding the target.

Figure 3 is a circuit diagram of one phototube and its preamplifier. There are two more identical units. Several general references were consulted in the design of these circuits. (13),(14),(15),(16),(17)

Figure 4 is a photograph of all three units complete, showing the lucite tubes and the framework by which the whole is fastened to the face of the oscilloscope. The lucite tubes were first shaped and then cemented to the 931-A phototubes by means of Canada balsam. The phototubes were

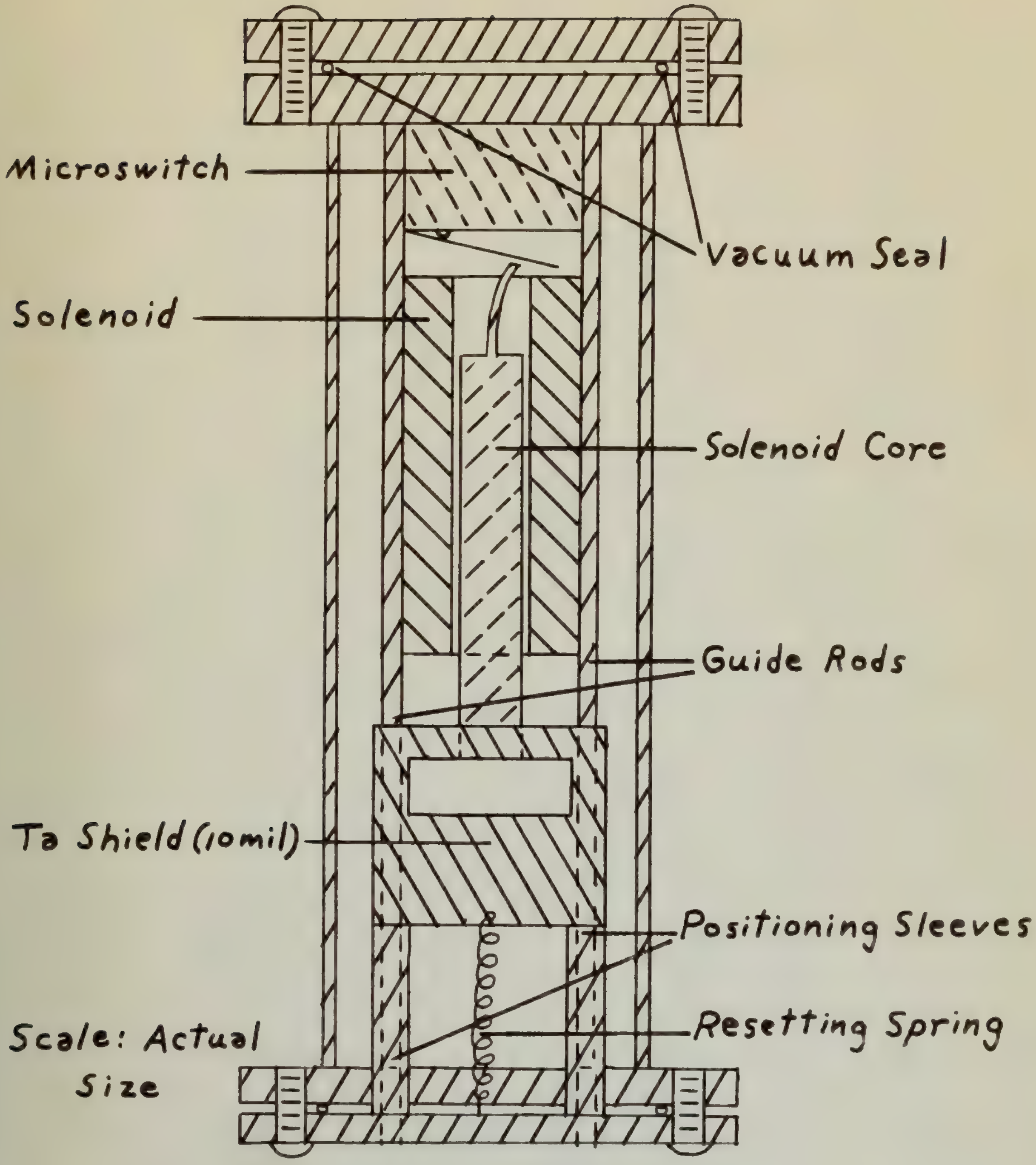

Figure 2. Cross-sectional sketch of shutter.

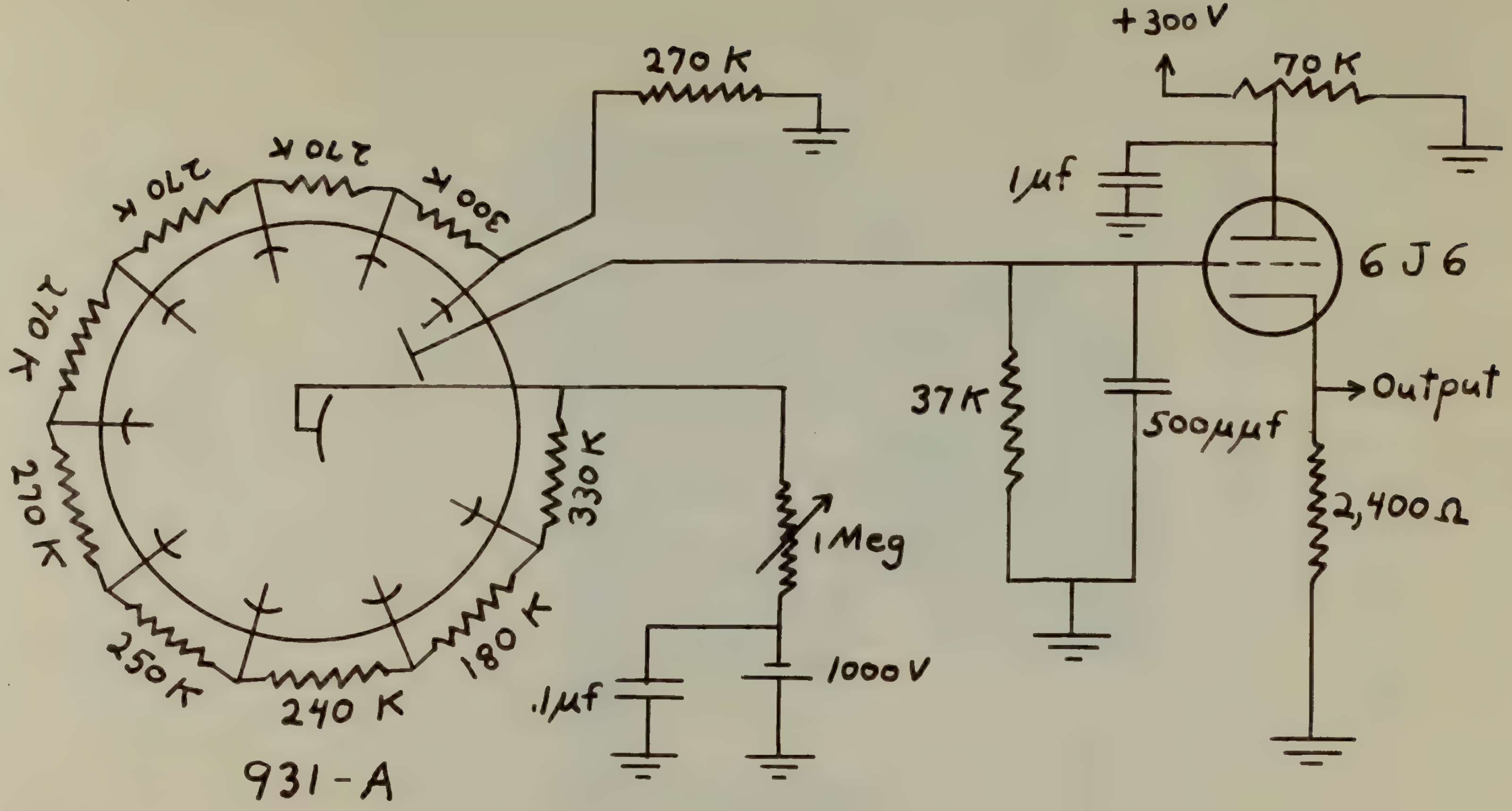

Figure 3. A typical phototube-preamplifier unit.

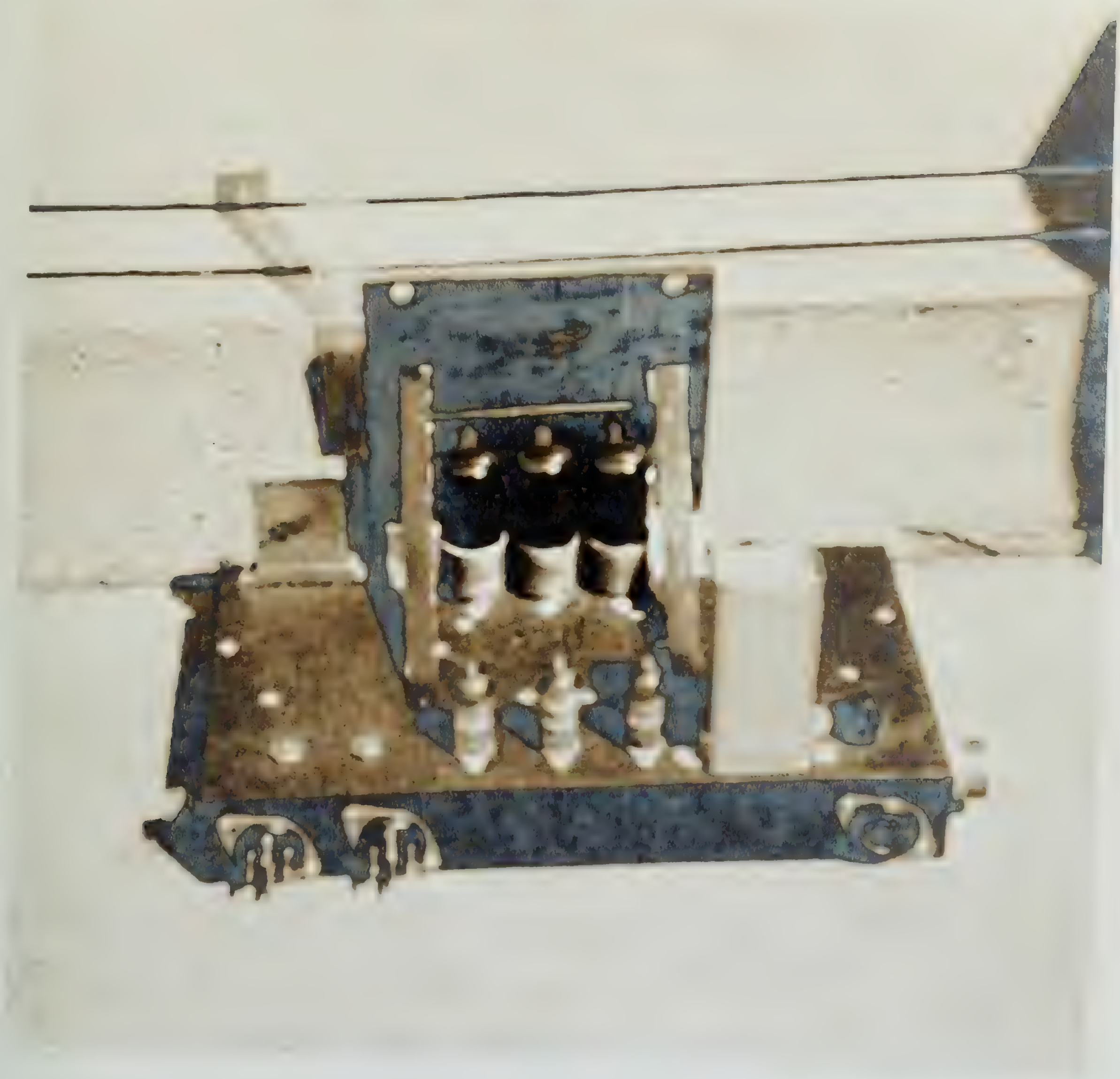

Figure 4. Photograph of complete phototube - preamplifier unit.

painted black to keep out undesired stray light. A pressure fit for the end of the lucite tubes against the face of the oscilloscope was found to be satisfactory. It should be noted that the variable resistances placed in the phototube circuits permit independent adjustment of the voltage across each phototube (within certain limits). This was found to be necessary since the 931-A tubes used did not have precisely the same characteristics as a function of voltage. It is imperative that the same number of counts be registered by each phototube from the same source of light impulses. By adjusting the voltage properly on each phototube it was possible to attain this desired condition.

Specific Experiments Performed

After this equipment was designed and constructed, it was decided to apply it to the problem of determining the half-lives of the two radioisotopes Al^{25} and Al^{26}, both of which are in the neighborhood of 7 sec. Since there was no sweep time as large as 7 sec. available on the oscilloscope, it became evident that the general method already described would have to be modified slightly for this problem. An auxiliary sweep circuit of the desired length could have been built, but this was decided against in favor of a much simpler idea. Instead of triggering a sweep across

the face of the oscilloscope the electron beam was left focussed on a spot directly under one of the lucite tubes connected to one of the phototubes. The other two phototubes were disconnected completely. Periodically a voltage was applied to the horizontal deflection plates of the oscilloscope to move the spot out from under the lucite tube of the active phototube. This method had the definite advantage that all of the pulses from the Geiger tube were counted while the electron beam spot was focussed under the lucite tube.

The periodic application of a deflecting voltage to the horizontal deflection plates of the oscilloscope was accomplished as follows. A scaler was set to a scale of 64 and then allowed to count the 60 cycle A. C. line frequency. The resulting pulse every 64/60 of a second was fed into an external register. The external register had a sliding metal contact which made contact with the rotating wheel of the mechanical register. However, at definite intervals around the wheel scotch tape was placed so that the electrical contact was broken periodically. In particular the scotch tape was arranged so that the electrical contact was made for 2(64/60) seconds then broken for 3 (64/60) seconds. For convenience hereafter (64/60) sec. will be spoken of as one time unit. With a 22 1/2 volt battery in series with the electrical contact and the horizontal deflection plates of the oscilloscope, the photo-

tube counted for 2 time units, did not count for 3 time units, counted for 2 time units, etc.

A minor difficulty arose when it was found that the pulse coming from the preamplifier following the phototube was not large enough to trigger a Tracerlab autoscaler. It had triggered an Atomic Instrument Co. Model 1030 scaler very nicely, but this scaler was not available for the purpose of counting the phototube pulses. Consequently a two-stage amplifier was designed and constructed to amplify the preamplifier pulse enough so that the autoscaler would record it. The circuit diagram of this amplifier is given in Figure 5.

Utilizing the modifications mentioned above, the following experiment was performed. A target of isotopically pure* Mg^{24} was bombarded with protons of energy 224 kev. This energy is at a resonance peak for $Mg^{24}(p,\gamma)Al^{25}$. After bombarding for thirty sec. a switch was thrown actuating the solenoid which pulled the shutter up, interrupting the Van de Graaff beam and closing the microswitch. The microswitch's closing actuated a relay which lifted a lead shield from between the target and an active Geiger tube. The Geiger tube then sent pulses to the vertical plates of the

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*Obtained from Carbide and Carbon Chemicals Division, Y-12 Area, Oak Ridge National Laboratory, upon allocation from the Atomic Energy Commission.

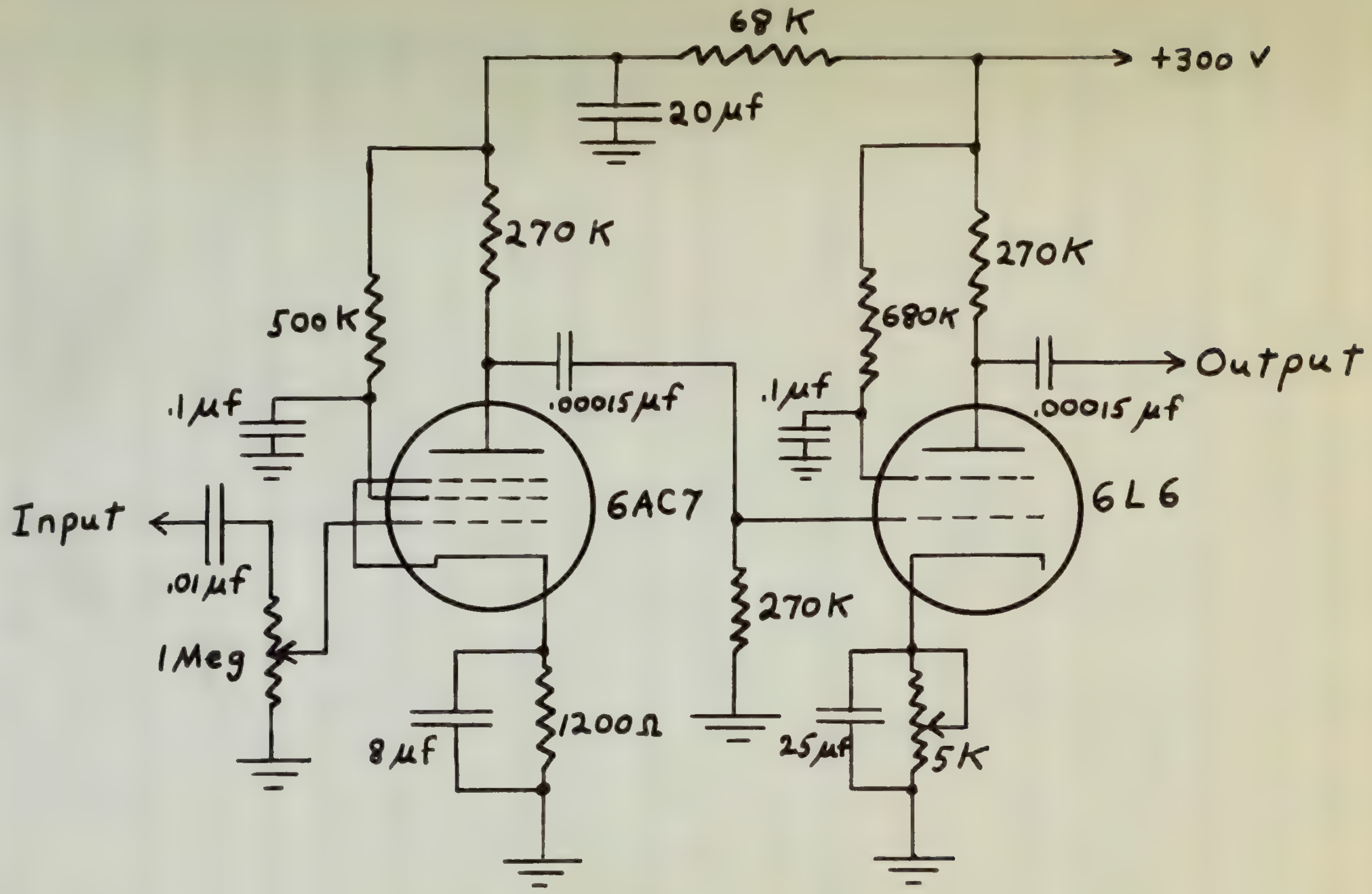

Figure 5. Circuit diagram of amplifier.

oscilloscope and the phototube counted these pulses for 2 time-unit intervals. During the three time-units delay the number of pulses registered in the preceding two time units was recorded. This sequence of events was repeated many times to get sufficient counts to insure a low probable error. The data so obtained are given in Appendix I.

A similar experiment was then performed with a target of Mg^{25}, using protons of energy 360 kev. This energy is at a resonance peak for $Mg^{25}(p,\gamma)Al^{26}$. The data obtained in this experiment are given in Appendix II.

Analysis of Data and Discussion of Results

In the first experiment described the nuclear reaction occurring is known(29) to be $Mg^{24}(p,\gamma)Al^{25}$ so the radioisotope whose activity would be measured is Al^{25}. All of the data obtained for the first time interval (2 time units) were added together as were those for all the other time intervals. This gave ultimately five points on the decay curve of Al^{25}. Figure 6 is a plot on semi-log graph paper of the results obtained from the data listed in Appendix I. The variations plotted are one standard deviation in length. The background counting rate was measured approximately in the middle of each experiment. While taking background data the shutter was closed, with the Van de Graaff beam bombarding it, and the lead shield was raised. Before

starting to record the background counts, the induced activity of the target was allowed to decay for one minute.

The value of a standard deviation was obtained in the following manner. Suppose the total number of counts for a given time interval to be N. If there were no background counts, the standard deviation, σ, would be $\sqrt{N}$. The fact that there are background counts must be considered, however. Suppose that the number of background counts in a given time interval is B. Then the standard deviation will be

$$\sigma = \sqrt{N + B} \qquad (11).$$

To actually determine the half-life of Al^{25} from the data in Appendix I a line was fitted to the data using the method of least squares. A short derivation of the theory of this method is given.(18)

Suppose a set of N points, of which only the y coordinate is susceptible to error, when plotted on graph paper suggest a linear relationship with equation

$$y = mx + k \qquad (12).$$

Now, let d_i be the difference between the ordinate of the ith point and the corresponding ordinate of the line. Denote the weight of y_i by w_i. The method of least squares assumes that the best fit will be obtained when the sum of the $w_i(d_i)^2$ is a minimum. This may be expressed as follows:

$$\sum_i w_i d_i^2 = \sum_i w_i \left[y_i - (mx_i + k)\right]^2 \qquad (13)$$

is to be minimized.

Expansion of (13) leads to

$$\Sigma w_i d_i^2 = \Sigma w_i(y_i^2 + m^2x_i^2 + k^2 - 2my_ix_i - 2ky_i + 2kmx_i) \qquad (14).$$

This may be further simplified to

$$\Sigma w_i d_i^2 = k^2 \Sigma w_i + 2mk \Sigma w_i x_i + m^2 \Sigma w_i x_i^2 - 2k \Sigma w_i y_i - 2m \Sigma w_i x_i y_i + \Sigma w_i y_i^2 \qquad (15).$$

Consider this now as a function of the two variables m and k. Say $\Sigma w_i d_i^2 = f(m,k)$. Now to determine the minima of f (m,k) as functions of m and k respectively one needs only to take the partial derivatives of f (m,k) first with respect to m and then with respect to k and in each case to set the result equal to zero. This gives the following two equations in the two unknowns m and k:

$$\frac{\partial f(m,k)}{\partial m} = 2k \Sigma w_i x_i + 2m \Sigma w_i x_i^2 - 2 \Sigma w_i x_i y_i = 0$$

$$\frac{\partial f(m,k)}{\partial k} = 2k \Sigma w_i + 2m \Sigma w_i x_i - 2 \Sigma w_i y_i = 0 \qquad (16).$$

The solution to these equations may be written down immediately by Cramer's rule and is

$$k = \frac{\begin{vmatrix} \Sigma w_i x_i y_i & \Sigma w_i x_i^2 \\ \Sigma w_i y_i & \Sigma w_i x_i \end{vmatrix}}{D}\ ; \quad m = \frac{\begin{vmatrix} \Sigma w_i x_i & \Sigma w_i x_i y_i \\ \Sigma w_i & \Sigma w_i y_i \end{vmatrix}}{D} \qquad (17)$$

where

$$D = \begin{vmatrix} \Sigma w_i x_i & \Sigma w_i x_i^2 \\ \Sigma w_i & \Sigma w_i x_i \end{vmatrix} \qquad (18).$$

This gives the solution in general.

Now in this case the actual equation of the radioactive decay being observed is

$$y = ke^{mx} \qquad (19)$$

where x is the time coordinate, y is the counting rate, and m is equal to $(-\lambda)$. To identify this situation with the straight line theory just developed one need only take the logarithm of both sides of (19) to get

$$\log_{10} y = \log_{10} k + (m \log_{10} e)x \qquad (20).$$

If one puts $y' = \log_{10} y$, $m' = m \log_{10} e$, and $k' = \log_{10} k$, equation (20) becomes

$$y' = m'x + k' \qquad (21)$$

which is then only the form already treated.

It has been shown(12) that the proper weighting factor, w_i', to use for the y_i' is $(2.303)^2\, y_i$. With y_i' substituted for y_i and w_i' substituted for w_i, equation (17) may be used to compute the constants m' and k' in equation (21).

The total number of counts, y_i, obtained in the ith time interval was plotted at the center of the interval. Thus it was the center of each time interval which was denoted as x_i. To be more precise one should use for x_i the quantity $\bar{x}_i$ given by

$$\bar{x}_i = \int_{x_0}^{x_f} x e^{-\lambda x}\, dx \Big/ \int_{x_0}^{x_f} e^{-\lambda x}\, dx \qquad (22)$$

where the limits of integration are from the initial x coordinate to the final x coordinate of the ith interval,

and λ is the decay constant of the radioactive material being measured. Note that an assumed value for λ is necessary to evaluate equation (22). Moreover the fitted value of λ depends on x_i ; hence a method of successive approximations must be used.

The more precise method of determining the x_i's is not necessary if the counting intervals are of uniform length, and only the slope of the decay curve is desired. The precise method should be used if one wishes to extrapolate the decay curve back to zero time.

During the actual conduction of the experiment it was observed that following the turning on of the count switch on the scaler, a brief period of time elapsed before any counts were registered. Thus the scaler seemed to have an inherent delay time between the time the count switch was turned on and counts were actually recorded. On the basis of this observation it was necessary to discard the data obtained for the first time interval since actually the scaler was not functioning properly for the full 2 time units. Thus only four points were used to determine the half-lives of the radioisotopes.

Table 1 is a summary of the Al^{28} data needed to compute the half-life. The y_i were determined from the data in Appendix I, and σ was computed by utilizing formula (11).

x_i (time units)	y_i (net counts)	σ_i	y'_i	w'_i ($\times 10^9$)	$x_i w'_i$ ($\times 10^9$)
6	3,192	± 66	3.50406	32.523	195.138
11	1,929	± 56	3.28533	7.176	78.958
16	1,070	± 47	3.02938	1.225	19.600
21	600	± 43	2.77815	.327	6.868
				41.251	300.544

x_i (time units)	y_i (net counts)	$x_i^2 w'_i$ ($\times 10^9$)	$x_i y'_i w'_i$ ($\times 10^9$)	$y'_i w'_i$ ($\times 10^9$)
6	3,192	1,170.828	683.775	113.962
11	1,929	868.536	259.403	23.582
16	1,070	313.600	59.376	3.711
21	600	144.648	19.554	.911
		2,497.614	1,022.108	142.166

Table 1. Summary of Data for Al^{25}.

Using Table 1 and equations (17) one may easily compute m' and k'. The quantity m' is computed to be −.04515 (time units)$^{-1}$, while k' comes out to be 3.77559. Now since $m' = m \log_{10} e = .434m$,

$m = -.04515 / .434 = -.1040 = .693 / H.L.$ (23).

From equation (23) the half-life of Al^{25}, H.L., is readily found to be 6.67 time units or 7.11 sec.

It has been shown(12) that an estimate of the standard

error of m' may be obtained from

$$(\text{S.E. in } m')^2 = C_{22}\,\sigma^2(\text{ext}) \qquad (24)$$

where

$$C_{22} = \Sigma w_i' \,/\, D' \qquad (25)$$

in which D' is the D defined by equation (16) with w_i' substituted for w_i and y_i' for y_i;

and

$$\sigma^2(\text{ext}) = \Sigma w_i' \, d_i^2 \,/(n-p) \qquad (26)$$

in which n is the number of points to be fitted, and p is the number of adjustable parameters. In this case n-p is 2. Application of equation (24) leads to S.E. in m' = ±.00300 and ultimately the S.E. in the half-life of Al^{25} = ±.20 sec. Thus the half-life of Al^{25} is reported as 7.11 ± .13 sec., where .13 = (.67)(S.E.) = probable error. Figure 6 is a graph of the decay of Al^{25}.

The data listed in Appendix II is summarized in Table 2. Computations precisely similar to these made for Al^{25} were performed for Al^{26}, indicating the half-life of Al^{26} to be 7.61 ± .21 sec., where the ± .21 sec. is probable error. Figure 7 is a graph of the decay of Al^{26}.

The values obtained by these experiments for the half-lives of Al^{25} and Al^{26} should now be compared with values reported by other research workers using different methods. Bradner and Gow(19) have reported the half-life of Al^{25} to be 7.3 sec. They bombarded $Mg^{25}O$ with protons from a linear accelerator and found an activity of 7.3 sec. which they

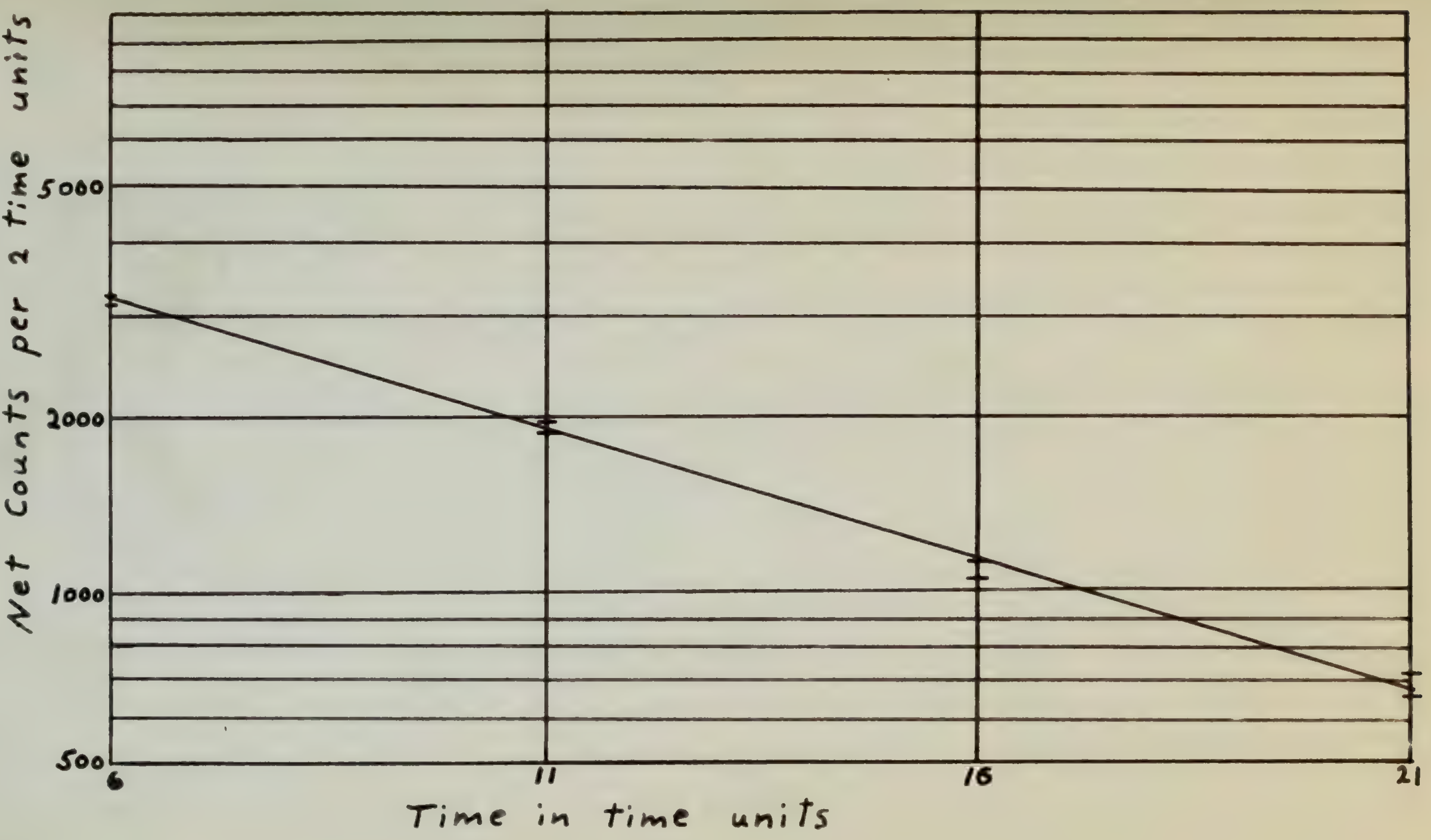

Figure 6. Decay curve of Al^{25}.

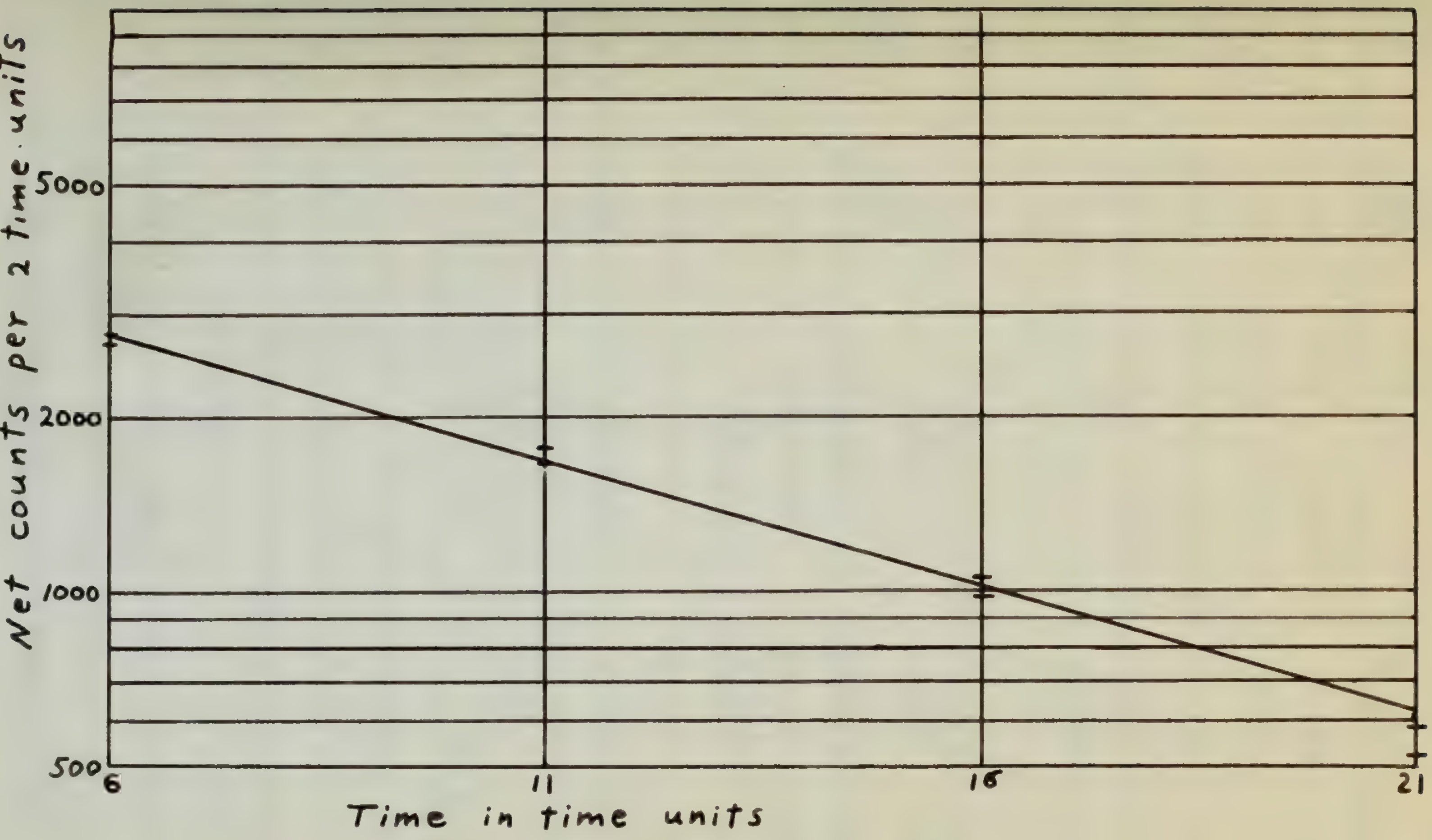

Figure 7. Decay curve of Al^{26}.

x_i (time units)	y_i (net counts)	σ_i	y_i'	w_i' ($\times 10^9$)	$x_i w_i'$ ($\times 10^9$)
6	2,713	± 58	3.43345	19.969	119.814
11	1,713	± 49	3.23376	5.026	55.286
16	1,008	± 41	3.00346	1.024	16.384
21	550	± 33	2.74036	.166	3.486
				26.185	194.970

x_i (time units)	y_i (net counts)	$x_i^2 w_i'$ ($\times 10^9$)	$x_i y_i' w_i'$ ($\times 10^9$)	$y_i' w_i'$ ($\times 10^9$)
6	2,713	718.884	411.375	68.562
11	1,713	608.146	178.782	16.253
16	1,008	262.144	49.209	3.076
21	550	73.206	9.553	.455
		1,662.380	648.919	88.346

Table 2. Summary of Data for Al^{25}.

attributed to the reaction Mg^{25}(p,n) Al^{25}. It is thus seen that the results of this experiment agree quite closely with those of Bradner and Gow for Al^{25}. Bradner and Gow did not give the details of their experimental arrangement, nor the energy of the bombarding protons, nor probable error in their result. There are very few reports in the literature listing a half-life for Al^{25}. This is undoubtedly due to the fact that only recently have separated isotopes of

Mg been available. The common procedure in the past has been to bombard a target of unseparated magnesium with protons. This gives a mixture of the two isotopes Al^{25} and Al^{26}, and since their half-lives are so close together, the decay curve obtained cannot in general be resolved into two components.

Quite in contrast to the case for Al^{25} there are many values reported in the literature for the half-life of Al^{26}. The latest value is 6.3 sec. and was reported by Bradner and Gow in the same article in which they reported on Al^{25}. The reaction they used in this case was $Mg^{26}(p,n)\ Al^{26}$ where again the protons were supplied by a linear accelerator. Other older values$^{(20)-(26)}$ in the literature for the half-life of Al^{26}, however, range from 7.0 sec. to 8.5 sec., with most of the values centering around 7.0 sec. Bradner and Gow have suggested that the 7.0 sec. half-life normally given for Al^{26} is probably a mixture of Al^{25} and Al^{26}. This may be true in some cases but it is difficult to see how it could possibly be true in others. For example, Perlman and Friedlander(20) used the reaction $Al^{27}\ (\gamma,n)\ Al^{26}$ which certainly should have given them almost pure Al^{26}. Any Al^{25} which they would have gotten would have come from the reaction $Al^{27}\ (\gamma,2n)\ Al^{25}$ which has a very small cross section compared to the (γ,n) reaction. The half-life reported by them for Al^{26} was

7.0 sec. Wäffler and Hirzel(21) have also used the Al^{27} (γ,n) Al^{26} reaction; they report the half-life of Al^{26} to be 7.2 sec. In a pioneer experiment in this field Frisch(22), exploring the reaction $Na^{23}(\alpha,n)$ Al^{26}, obtained a value of 7 ± 1 sec. for the half-life of Al^{26}. Huber et al(23), exploring the reaction $Al^{27}(\gamma,n)$ Al^{26}, obtained a half-life of 7.2 ± .5 sec. for Al^{26}. In all cases reported(23),(24),(25) where one would reasonably expect the true activity measured to be a mixture of Al^{25} and Al^{26} only a single decay curve has been observed. This would tend to indicate that the true half-lives of Al^{25} and Al^{26} are quite close together.

The value found in this experiment for the half-life of Al^{26}, 7.61 ± .21 sec., does not agree with the 6.3 sec. of Bradner and Gow. No explanation is offered for this discrepancy other than the fact that the value found in this work does agree with that reported by researchers(26) other than Bradner and Gow. One possible explanation is that there are two isomeric states of Al^{26} with quite close half-lives.

Discussion of New Method's Capabilities and Limitations

It is manifestly to be regretted that there was no opportunity to conduct an experiment which would have utilized the new method in its originally described manner.

The main reason for deciding to measure the half-lives of Al^{25} and Al^{26} instead of any other radioisotopes was the fact that this knowledge was desired in collaboration with some work at this university of [illegible] Taylor and [illegible] Burrell on measuring nuclear resonance peaks for the reactions Mg^{24} (p,γ) Al^{25} and Mg^{25} (p,γ) Al^{26}. The author feels certain that if time would have permitted the performance of another experiment, the apparatus described would have worked satisfactorily in its originally described way.

The main advantages of this new method are its simplicity of design, the fact that it utilizes mostly commercially available equipment, and its great flexibility of application over a wide range of half-lives, 1 millisec. to 1 min. For all half-lives longer than 1 sec. the adaptation used in the Al^{25} and Al^{26} experiments is probably more practical than the first-described method.

One of the limitations which should be mentioned includes the large number of runs which would be necessary to insure a small probable error using the first method. Since the half-life would be computed on the basis of only three points, these points would have to be good ones. Also if the method were to be used to measure half-lives shorter than approximately 10^{-3} sec., the Geiger tube should be replaced by a scintillation counter. This would be necessary

since Geiger tubes have dead times on the order of 10^{-4} sec. and the many coincidence counts would be lost. Actually since scintillation counter dead times are of the order of 10^{-8} sec., this method is capable of measuring half-lives on the order of 10^{-7} sec. if an auxiliary fast oscilloscope sweep were constructed, and if an electronic shutter of some type were utilized.

Another minor limitation is the fact that in the modification employed in the current experiments the number of counts obtained at a given voltage setting on the 931-A phototube is very sensitive to the gain control on the amplifier used. This made it necessary to calibrate the phototube part of the apparatus by feeding a known frequency pulse from a pulse generator into the vertical deflection plates of the oscilloscope and adjusting the gain control on the amplifier until the scaler connected to the output of the phototube recorded the correct number of counts. The variable controls were not touched again then during an entire experiment. In reality this is not a serious defect since all that is actually required is that the gain remain constant over the few seconds of each individual run.

There are several radioisotopes whose half-lives might profitably be checked by this new method. Some of these are listed below, together with the reported values of the half-lives.(27),(30),(31)

Isotope	Half-life (sec.)	Reaction	Q (mev.)
B^{12}	2.7, 2.2 x 10^{-2}	$B^{11}(d,p)B^{12}$	0.4
He^{6}	.85, .87, .8	$Be^{9}(n,\alpha)He^{6}$	-0.[illegible]
Li^{8}	.88, .89	$Li^{7}(d,p)Li^{8}$	-0.[illegible]
A^{35}	2.2, 1.84, 1.88	$Cl^{35}(p,n)A^{35}$	-6.6
Cl^{33}	2.8, 2.4	$S^{32}(d,n)Cl^{33}$	.65
S^{31}	2.9, 3.2	$P^{31}(p,n)S^{31}$	-6.0
Si^{27}	4.9, 4.5	$Al^{27}(p,n)Si^{27}$	-[illegible].4
N^{16}	7.3, 8	$N^{15}(d,p)N^{16}$	0.5
Mg^{23}	11.6, 11.9, 12	$Na^{23}(p,n)Mg^{23}$	-[illegible].5
N^{12}	12.5 x 10^{-3}	$C^{12}(p,n)N^{12}$	-18.5
Sc^{41}	.87	$Ca^{40}(d,n)Sc^{41}$	.33*
Ca^{39}	1.06	$Ca^{40}(\gamma,n)Ca^{39}$	-14.6*
P^{29}	4.6	$Si^{28}(d,n)P^{29}$	-0.80
K^{37}	1.3	$K^{39}(\gamma,2n)K^{37}$	-[illegible]
Ti^{43}	.58	$Ca^{40}(\alpha,n)Ti^{43}$	-8.6*
Cu^{58}	3	$Ni^{58}(p,n)Cu^{58}$	-10.5*
Kr^{97}	1-2	Fission	—
Rb^{90-94}	short	Fission	—
Ca^{41}	?	$Ca^{40}(d,p)Ca^{41}$	6.09

Of course, there are many other short-lived radioisotopes in addition to the ones listed.

*These values were computed using mass values as given by N. Metropolis and G. Reitwiesner, "Table of Atomic Masses", Argonne National Laboratory, 1950.

Another very interesting experiment which could be done would be to measure the half-life of Al^{26} from the reaction $Mg^{25}(p,\gamma)\ Al^{26}$ for different energies of the bombarding protons. Different values of half-lives at different energies would indicate the existence of isomeric states of Al^{26}. Curran and Strothers(23) performed this experiment with an unseparated Mg target in 1939, and their results suggest the possibility that indeed different half-lives might be found at different bombarding proton energies.

Summary

A new method of measuring short half-lives in the range from 1 millisec. to 1 min. has been described. This method has then been applied to the problems of determining the half-lives of Al^{25} and Al^{26} with the following results: Al^{25}-7.11 ± .13 sec. ; Al^{26}-7.61 ± .21 sec. Some capabilities and limitations of the method have been discussed and future applications have been suggested.

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Appendix I

Data for Mg^{24} (p,γ) Al^{25} experiment.

Background: 1024 counts in 467 sec.

All time intervals 2 time units or 2(64/60) sec. long.

The numbers recorded are 2 times the actual cumulated counts.

1st	2nd	3rd	4th	5th
92	162	180	[illegible]	[illegible]
72	96	120	[illegible]	132
112	[illegible]	252	[illegible]	[illegible]
94	132	170	216	200
76	116	140	174	190
82	148	216	222	242
54	84	138	158	170
64	108	152	132	178
38	86	116	144	164
136	214	280	296	332
150	172	208	250	272
170	292	334	356	360
98	150	218	274	314
78	136	154	174	190
54	92	118	118	126
90	182	230	266	286
214	362	392	452	470
134	172	198	222	250
172	304	348	384	408
88	204	240	280	310
18	22	28	38	42
98	116	134	144	180
80	110	134	148	174
80	132	182	226	236
[illegible]	204	260	290	304
[illegible]	66	110	137	144
134	206	252	234	272
12	68	78	102	111
110	214	262	272	302
230	274	300	324	330
128	170	200	141	158
88	96	116	132	130
50	74	76	86	80

1st	2nd	3rd	4th	5th
46	74	96	104	112
40	82	102	102	116
12	20	24	32	32
132	256	304	340	358
136	196	230	264	270
116	174	196	250	250
12	12	22	32	44
30	38	42	48	64
82	118	134	160	174
46	90	140	142	150
122	112	186	212	220
78	124	150	160	160
38	64	94	134	166
72	88	114	172	208
116	178	218	250	264
120	212	282	312	330
124	186	194	200	212
58	96	108	144	178
60	102	122	132	140
34	140	204	210	230
30	74	102	122	138
62	96	110	124	128
116	212	274	310	330
76	116	150	166	172
112	160	196	170	212
76	136	168	196	206
66	112	168	192	214
112	112	116	160	180
114	182	208	242	274
130	232	304	300	330
96	150	136	112	132
76	122	142	170	192
90	116	182	208	236

24	40	32	30	44
64	96	110	132	166
30	54	90	116	118
38	112	172	202	226
102	112	192	228	240
96	178	214	242	268
76	138	160	190	216
62	110	132	130	258
32	90	128	138	164
88	130	172	170	216
88	134	150	180	214
22	40	68	66	98
38	60	130	140	156
72	136	160	152	180
108	158	198	210	216
128	174	224	270	294
108	206	262	288	290
108	148	162	174	212
30	72	84	96	96
18	38	32	60	60
58	150	176	172	172
68	150	138	184	216
12	58	72	106	124
60	122	172	202	220
24	72	72	72	76
72	134	150	162	190
32	68	138	144	118
136	160	224	136	266
92	104	152	200	256
94	112	162	182	200

72	114	154	218	236
58	156	164	180	212
86	180	228	242	252
124	168	200	210	236
48	156	260	254	284
108	168	234	290	314
90	178	272	304	310
72	202	222	208	270
206	174	284	250	280
44	128	172	172	154
58	200	230	280	250
110	168	230	242	246
82	136	160	176	192
144	236	314	262	412
90	148	210	236	296
112	170	208	258	276
96	204	250	314	376
46	118	142	176	188
126	160	232	208	304
114	228	242	292	292
72	174	200	244	250
132	218	298	310	372
76	186	212	244	272
112	192	264	282	302
142	214	282	318	368
66	256	278	300	336
112	196	226	256	312
156	238	336	348	356
136	226	262	370	342
192	276	338	344	416

	1st	2nd	3rd	4th	5th
Sums	11,308	18,872	23,910	27,230	29,790
÷ 2	5,654	9,436	11,955	13,615	14,895
Differences	5,654	3,782	2,519	1,660	1,280
- E. V.	5,064	3,192	1,929	1,070	690

Appendix II

Data for Mg^{25} (p,γ) Al^{26} experiment.

Background: 734 counts in 1,335 sec.

All time intervals 2 time units or [illegible] sec. long.

The numbers recorded are 2 times the actual cumulative counts.

1st	2nd	3rd	4th	5th	1st	2nd	3rd	4th	5th
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

110

32	44	64	68	76	32	56	68	80	92
36	56	70	76	82	30	46	62	68	72
16	52	66	78	88	20	44	48	58	68
34	54	72	84	90	16	36	52	66	72
40	48	62	68	74	36	68	88	94	96
28	62	74	78	88	42	56	64	72	76
30	76	88	96	106	34	40	50	56	60
34	62	88	102	110	16	32	36	44	44
10	28	40	44	44	20	44	54	84	98
38	62	80	88	96	36	64	82	92	100
36	52	62	68	82	36	52	58	68	72
40	62	70	84	94	36	44	66	90	100

	1st	2nd	3rd	4th	5th
Sums	9,134	15,260	19,386	22,102	23,902
÷ 2	4,567	7,630	9,693	11,051	11,951
Differences	4,567	3,063	2,063	1,358	900
- B. G.	4,217	2,713	1,713	1,008	550

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